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A GRAVITY SURVEY ON ASO CALDERA KYUSHU DISTRICT JAPAN (I)

By

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Abstract

On Aso Caldera, gravity surveys have been made by using a Worden gravimeter from 1964 to 1965, in order to investigate the problem, whether there exsists or not a cecular change in gravity value connected with volcanic activities, and to get clues for figuring out the subterranean structure of this caldera.

In this paper, the gravity values observed at each station and the distribution of Bouguer anomalies are reported.

The distribution of Bouguer anomalies shows that the low gravity anomaly decreasing toward the center of the caldera is very conspicuous. The iso-anomaly contour lines conform to the caldera shape, and the relative anomaly at the center of Aso caldera to the neighbour amounts to about -20 mgal. This fact shows that Aso caldera is characterized by strong negative anomalies in contrast to the outer somma part and it can be classified as "low anomaly type caldera" such as Kutcharo caldera lake or Aira caldera of the so-called Krakatau type.

Comparing the gravity values obtained by the present surveys with the ones obtained by the Earthquake Research Institute in 1964 and by the Geographical Survey Institute in 1959, it is concluded that there was no significant secular change in gravity value during the period from 1954 to 1964. And further discussions on atmospheric pressure and temperature effects on the Worden gravimeter are made.

1. Introduction

Since 1928, in the Volcanological Laboratory of Kyoto University, seismometric, geomagnetic and geodetic observations have been continuously carried out in connection with the activity of Volcano Aso.

On the other hand, in 1954, gravity survey on Volcano Aso was carried out by the Earthquake Research Institute [E. R. I.] (Tuboi et al 1954, 1956) along the route for the precise levels belonging to the Geographical Survey Institute [G. S. I.] and our Laboratory. In this survey, the observing points in Aso Caldera were 13 in number. Five of them were the bench marks belonging to the G. S. I., distributed in this caldera from east to west, and eight of them were our Laboratory's which had been set along the road from the foot (Bōchū) to the crater of Nakadake.

Though the number of observing points was not sufficient to discuss the gravimetric feature of this caldera, relatively low gravity anomalies were found in Aso caldera. In 1959, another survey of gravity was carried out by the G.S.I. along the same route and similar results were obtained.

I. Yokoyama (1963, b) discussed the character of Aso caldera in the gravimetric point of view, by using these data, and he concluded that Aso caldera is "low anomaly type caldera" such as Kutcharo caldera lake (Yokoyama, 1958) or Aira caldera (Yokoyama, 1961) of the so-called Kurakatau type.

Then, in the period from November 1964 to April 1965, more precise and numerous gravity surveys have been made by us to investigate the problem, whether or not there exsist secular change of gravity or local change connected with volcanic activities, and also to get clues for figuring out the subterranean structure of this caldera.

2. Observation and Results

Worden gravimeter No. 127 has been used in the present surveys. Most of the observations were made on the bench marks for precise levels and triangulation points in Aso caldera. The route of bench marks for precise levels belonging to the G.S.I. traverses this area from east to west [No. 1 to No. 16 in Table 3], and the bench marks belonging to our laboratory had been set along the road from the foot (Bōchū) to the crater of Nakadake [No. 17 to No. 44 in Table 3] and also Kumamoto Prefecture's ones had been set along the road from Akamizu to the foot of Kishimadake [No. 45 to No. 54 in Table 3]. Moreover in Aso caldera had been distributed the 3rd and 4th order triangulation points numbering about 50, and 27 points of them have been made the present survey. Another observing points were settled on the road or railway platform, of which heights were known accurately. Collectively, our observing points amounted to 95, and they were distributed every 3 km on Aso caldera except the south-eastern part.

Observing points are shown in Fig. 1.

The accuracy of gravity anomaly mainly depends upon that of the heights of the observing points. The heights of the bench marks are known very acculately. Consequently, provided there were no observing errors, the gravity anomaly at the bench marks would be accurate within 0.01 mgal. As the heights of triangulation points are determined to the degree of 30 cm, the accuracy of their anomalies may be 0.1 mgal.

For the method of measurement, the loop method was used, and the looping was closed within two or three hours in most cases. All the observed

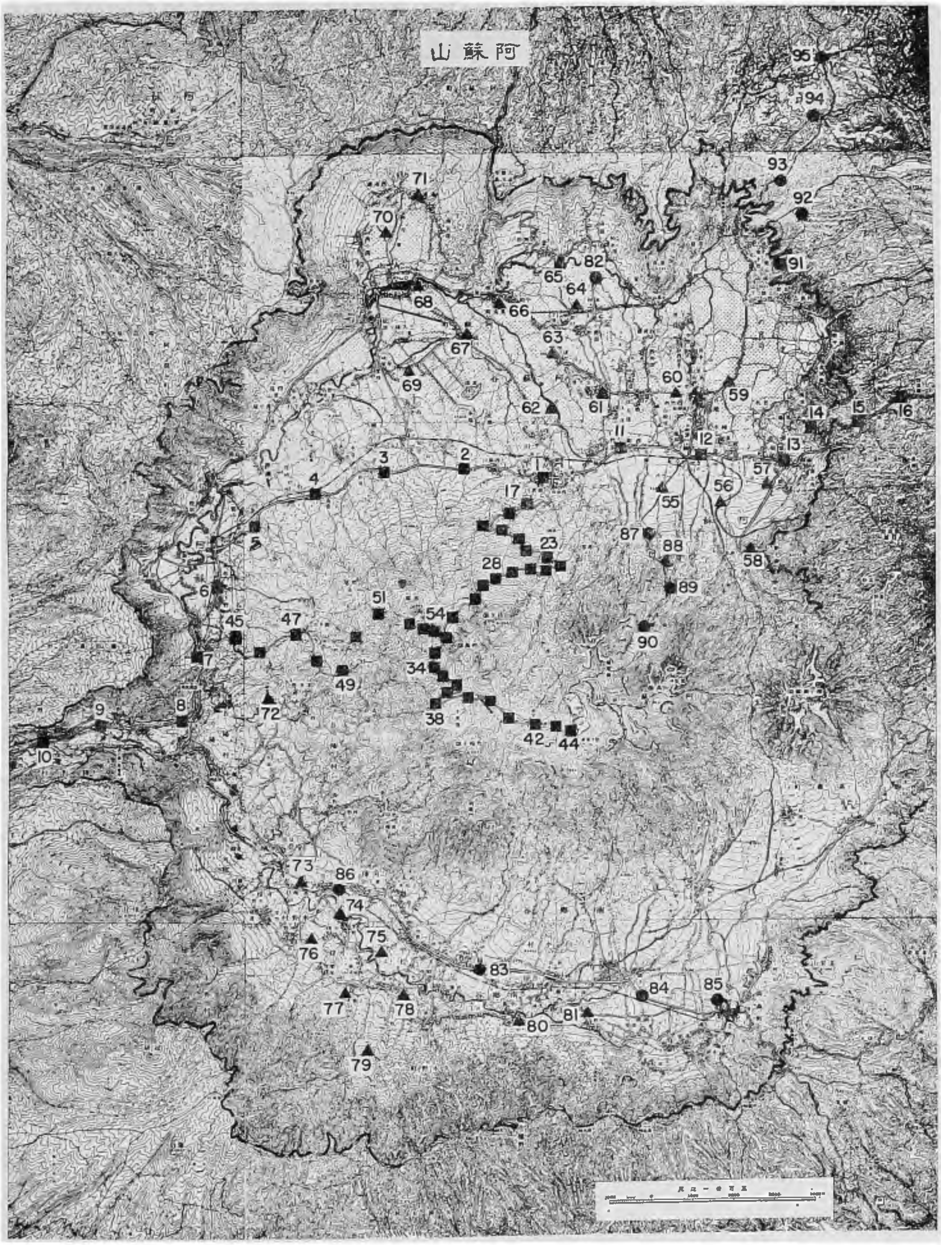

Fig. 1. Distribution of the gravity stations at Aso Caldera.
■ denote bench mark for precise levels.
▲ denote triangulation point.
● denote another station.

gravity values were deduced to the value determined at the local pendulum station at Kumamoto University in Kumamoto City. The gravity value of this local pendulum station was determined by the G.S.I. in 1963 (Fujii et al, 1964) as

$$g=979.56555 \text{ gal.}$$

The location of the station is as follows:

φ: 32°48.8′N

λ: 130°43.8′E

H: 22.84 m

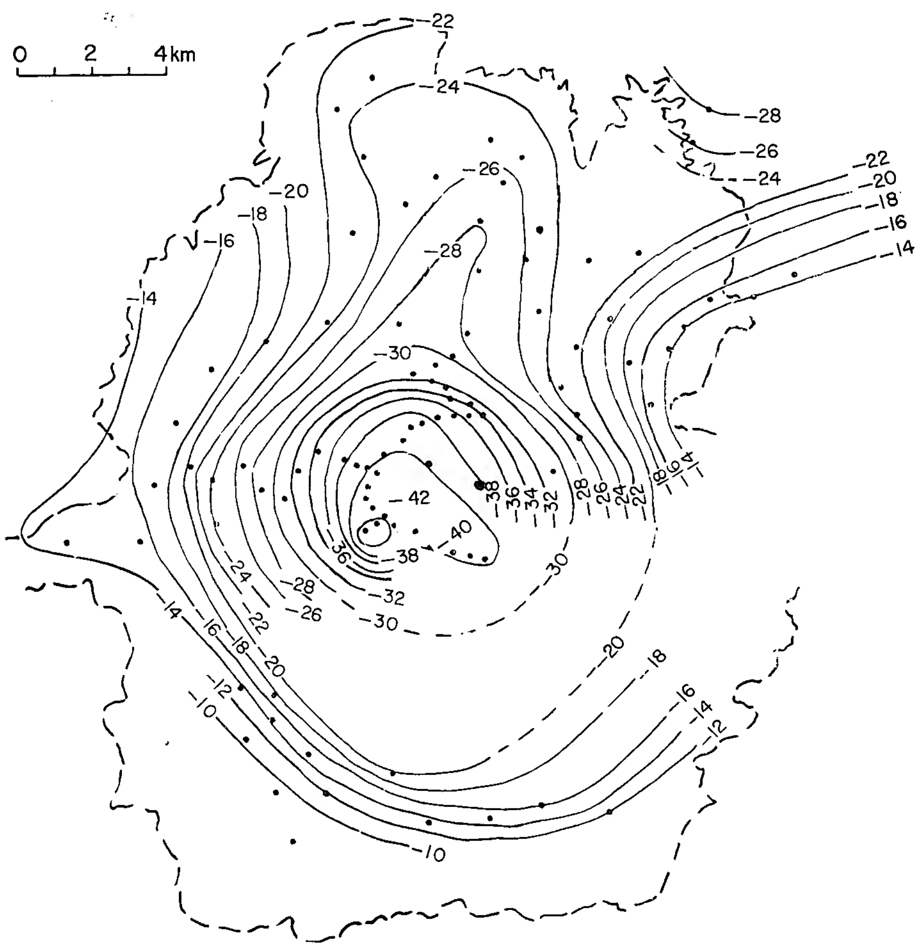

Fig. 2. Distribution of the Bouguer anomalies in Aso Caldera. (unit in mgal)

The observed gravity values at the bench marks were corrected for the earth's tides, but those at another points were not corrected. For the calculation of gravity anomalies, the vertical gradient of gravity: $\partial g/\partial z$ and the density of the earth's crust were assumed as 0.3086 mgal/m and 2.67 gr/cc respectively, and terrain correction was omitted. For the normal gravity value, the international formula was used.

All the observed gravity values and calculated Bouguer anomalies are tabulated at the end of the article [Table 3] and the latter are shown in Fig. 2.

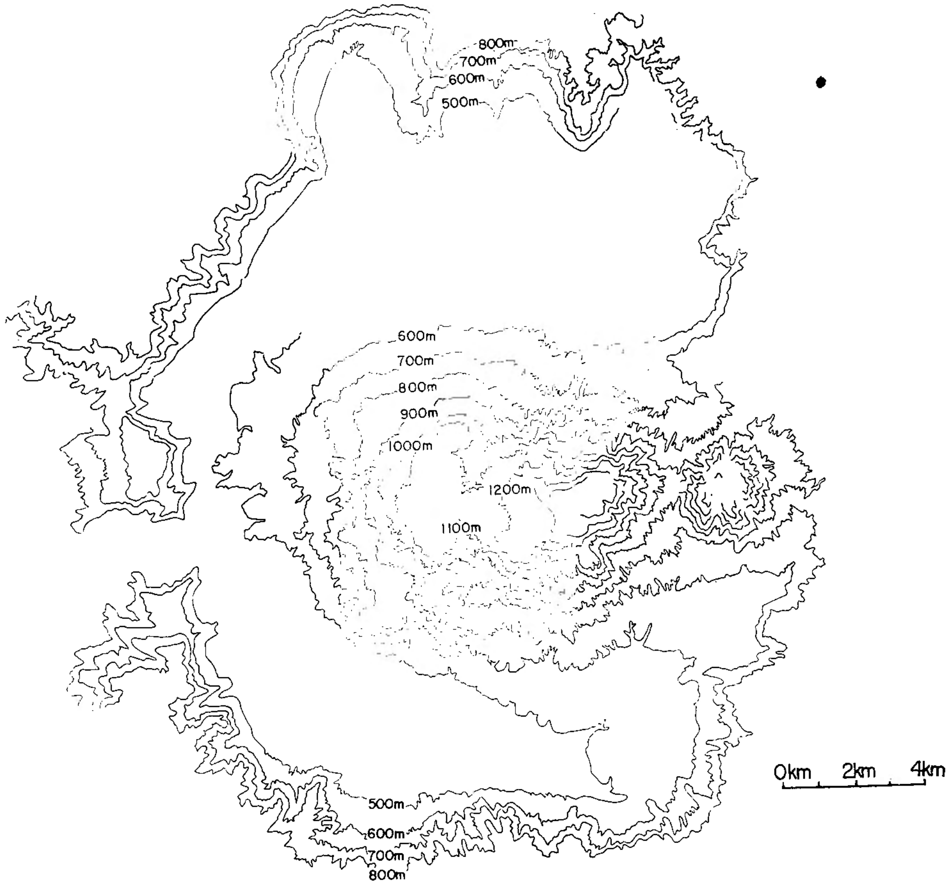

Fig. 3. Topographic contours in meter.

3. Discussion and Conclusion

A) Bouguer anomalies in Aso caldera

From the distribution of Bouguer anomalies, it seems that Aso caldera is characterized by strong negative anomalies reaching about −40 mgal at its center, gradually decreasing toward the center of the caldera.

I. Yokoyama proposed (1963 a. b.) that the Bouguer anomalies in calderas could be classified into two types : (1) low anomaly, that is Kutcharo type, and (2) high anomaly, that is Ooshima type. Aso caldera belongs to the low anomaly type which has been pointed out by I. Yokoyama (1963 a).

In order to discuss the detailed subterranean structure from the Bouguer anomalies, we must carry out the terrain corrections. By a rough estimation for terrain effects, it reaches 4 mgal at the highest point on the central cone, 2~3 mgal at the point on the half way or somma part and less than 1 mgal at the foot or atrio. Consequently, it may be said that terrain corrections have no essential effects on the contour lines of Bouguer anomalies.

As fiigure 2 has already shown, contour lines of Bouguer anomaly are similar to the topographic feature of this caldera except the north-eastern area. And also, iso-anomaly lines are concentric with the center of caldera. On the north-eastern side about 20 km distant from Aso caldera, there is situated Kujū Volcano. Therefore, the irregular area of the iso-anomaly line is considered to be effected by the subterranean structure of Kujū Volcano. The Bouguer anomalies of the northern part of caldera Aso-atrio are relatively lower than the southern part Nango-atrio. Assuming that the distribution of coarse material is responsible for the negative gravity anomalies, it seems that there is more coarse material in the Aso-atrio than Nango-atrio.

In August 1965, another gravity survey in the south-eastern area of Aso caldera and somma region was carried out in cooperation with the E. R. I. by using the Worden and La Coste & Romberg gravimeters. Therefore more detailed discussions will be made in future paper.

B) Secular change in gravity

If there were any change in the distribution of subterranean materials, there would occur some gravity change in that vicinity, and it must be observed by repeating measurement of gravity with sufficient accuracy. A volcanic region is one of the most probable regions considered to be liable to change the distribution of materials. Namely, some movement of magma forerunning volcanic eruption or some lava-effusion causes change of distribution of materials, and consequently brings some change in gravity.

Up to the present, the change of gravity at the area of Volcano Mihara in Ooshima of Izu islands was reported by K. Iida (1951). Lately, Y. Fujii (1964, b) pointed out that the gravity in the same area changed by 0.9 mgal at greatest during the period from 1950 to 1963. And he concluded that this fact associated with the activity of Volcano Mihara during 1950 to 1951. So far as we know, gravity surveys were made twice in the area of Aso volcano as described in the section 1 : one was carried out by the E. R. I. in 1954 with a Worden gravimeter, and the other was accomplished by the G. S. I. in 1959 using a North American gravimeter. Then, it is very interesting and significant that we try to compare our observed values with the above mentioned data, which were determined about 10 years ago. But the data available for comparison are limitted to only Route A (from the Kumamoto Univ. Base station to B. M. 1902 along the route for precise levels belonging to the G. S. I.) and B (from B. M. 1896 [Bōchū] to the crater of Nakadake along the route for precise levels belonging to Kyoto Univ.)

Though all gravity values compared are those just on the bench marks, prior to comparison, some corrections need to be made because the height and position of some bench marks were slightly changed by reburying, re-establishment and removal of the bench marks during the period of these surveys.

Every gravity value of respective surveys was adjusted for reference to the gravity value on the block of the seismograph room in the faculy of science, Kumamoto University, which was assumed to have suffered no gravity

Table 1. Comparison of gravity values along Route A.

Station	E. R. I. 1954 Worden No. 60	G. S. I. 1959 North American	Kyoto Univ. Worden No. 127	W-127 -W-60	N. A. -W-60	Height
Kumamoto Univ. Base	979. 565.55 (gal)	979. 565.55 (gal)	979. 565.55 (gal)	(mgal)	(mgal)	(m)
B. M. 1874	564.64	564.63			−0.01	14.3
1876	566.16	566.37			+0.21	23.5
1878	566.43	566.65			+0.22	57.8
1880	561.59	561.75			+0.16	61.0
1883	545.38	545.41			+0.13	95.4
1885	534.79	535.04			+0.25	127.1
1887	510.83	511.18	510.67*	−0.16	+0.35	219.1
1888		495.83	495.46			295.3
1889	478.39	478.78	478.37*	−0.02	+0.39	379.8
1890		462.98	462.47			458.8
1891		460.87	460.50			470.-
1892	460.42	460.84	460.32*	−0.10	+0.42	477.2
1893		45.671	456.17			488.4
1894	446.02	446.41	445.80*	−0.22	+0.39	519.6
1895		440.67	440.30			530.3
1896	439.62	440.01	439.54*	−0.08	+0.39	535.1
1897		444.38	443.93			528.0
1898	447.18	447.57	446.99	−0.19	+0.39	536.9
1899	452.33	452.97			+0.64	545.0
1902	414.78	415.25			+0.47	745.7

* Bench marks were moved, height reductions were made.

change during the period of these surveys. The comparison along Route A is shown in Table 1.

It seems clear that the values independently obtained by two Worden gravimeters are comparatively similar to each other at every station as shown in above Table 1. On the other hand, it is noticeable that there exsist some systematic differences between the values obtained by two Worden gravimeters and those by the North American gravimeter, and yet they don't necessarily depend on gravity difierence but rather on the height of the station.

Formerly, a similar result has been obtained by one of the present writers when the measurement of gravity was carried out at the top and foot of Mount Hiei by using two Worden gravimeters and La Coste & Romberg gravimeter. Why does such a discrepancy happen at the time of measurement at high stations?

Following causes can be considered which bring such a systematic discrepancy. Firstly, the scale values of either or both gravimeters may be not correct, then it will bring the systematic discrepancy in proportion to gravity difference. Secondly, one type of gravimeter may be more affected by atmospheric pressure than others, and so it may give rise to some errors. If it be true, the discrepancy will depend on the height of observing point. Lastly, either type of gravimeter may be influenced by external temperature, then the discrepancy will depend on the height to a certain degree. Besides, there may exsist many other unknown causes.

On the other hand, it has been suggested by Gantar, Morelli (1962), that the effect of the external pressure variations related to the different heights of the station is not always negligible, and height correction, the order of 0.1 to 0.2 mgal per 1000 meters, is to be applied as positive to the gravity difference (with sign) if the height increases. Moreover, G. Inghillerr (1959) pointed out that the effect of external temperature on scale value of Worden gravimeters could not be ignored, and was order of about 0.1% for each 10°C of thermic variation. Considering the fact that at high stations, the gravity values obtained by the Worden gravimeter were always lower than those obtained by the North American or La Coste & Romberg gravimeter, it may be said that the discrepancy obtained may be due to the both effects of the external pressure and temperature variation owing to the increasing of height.

Then, we have two sets of data by the E. R. I. and by us along Route B. But, even if it is assumed that the Worden gravimeter is liable to be influenced by atmospheric pressure and external temperature, comparison of gravity values in Rout B may not cause considerable errors and lose its significance under the following consideration. Both effects on the two Worden gravimeters are of same order because they showed well similar values in Route A. Unfortunately, however, positions of some bench marks were a little moved owing to the expansion of the road during the period from 1954 to 1964. But the height reductions were made enough correctly by using sufficiently accurate data of the leveling. The results of comparison are shown in Table 2.

Table 2. Secular change in gravity along Route B.

Observation Station	E. R. I. 1954 Worden No. 60	Kyoto Univ. Worden No. 127	Difference
B. M. 1896	979. 439. 54 (gal)	979. 439. 54 (gal)	(mgal)
Kyoto Univ. B. M. 1	429. 09	429. 30	+0. 21
2	416. 56	416. 63	+0. 07
5*	385. 86	386. 06	+0. 20
7*	359. 01	359. 02	+0. 01
10*	324. 06	323. 80	−0. 26
13	311. 90	311. 55	−0. 35
14	299. 18	298. 92	−0. 26
15	283. 59	283. 45	−0. 14

* Bench marks were moved during the period from 1954 to 1964.

Seeing above Table 2 it can be said that there has been no remarkable secular change in gravity during 10 years from 1954 to 1964, though a little systematic difference may be seen.

From above discussion, it is pointed out that we must pay much attention to the pressure and temperature effects on the behaviour of the gravimeter at the time of comparison of gravity value obtained by different gravimeters for the purpose of researching secular change in gravity.

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Table 3. Gravity Values and Bouguer Anomalies at all stations in Aso caldera.

No.	Station	φ	λ	H(m)	γ(gal)	g(gal)	$\Delta g_0''$ (mgal)
					979.	979.	
1	B. M. 1896	32°55.8′	131°04.8′	535.09	572.71	439.54	−27.83
2	1895	32°55.9′	131°03.6′	530.18	572.84	440.34	−28.13
3	1894	32°55.9′	131°02.3′	520.07	572.84	445.64	−24.82
4	1893	32°55.6′	131°01.3′	488.03	572.44	456.27	−20.09
5	1892	32°55.2′	131°00.3′	477.08	571.89	460.34	−17.63
6	1891	32°54.4′	130°59.7′	469.49	570.79	460.65	−17.72
7	1890	32°53.5′	130°59.4′	458.75	569.55	452.49	−16.75
8	1889	32°52.6′	130°59.2′	381.32	568.32	477.91	−15.34
9	1888	32°52.6′	130°57.9′	295.26	568.32	495.48	−14.71
10	1887	32°52.4′	130°57.0′	222.38	568.05	509.67	−14.60
11	1897	32°56.2′	131°05.8′	528.30	573.25	443.85	−25.40
12	1898	32°56.1′	131°07.2′	536.87	573.12	446.99	−20.44
13	1899	32°56.0′	131°08.6′	543.56	572.99	452.25	−13.74
14	1900	32°56.4′	131°08.8′	615.13	573.54	436.08	−16.36
15	1900−1	32°56.5′	131°09.5′	748.40	573.67	410.08	−16.26
16	1901	32°56.8′	131°10.2′	772.05	574.09	407.06	−15.05
17	B. M. Kyoto Univ. No. 1	32°55.5′	131°04.6′	575.01	572.30	429.30	−29.80
18	No. 1½	32°55.3′	131°04.1′	608.86	572.03	420.90	−31.27
19	No. 2	32°55.2′	131°03.9′	629.54	571.89	416.63	−31.32
20	No. 2½	32°55.1′	131°04.0′	656.80	571.76	410.65	−31.81
21	No. 3	32°55.0′	131°04.2′	673.59	571.62	406.64	−32.38
22	No. 3½	32°54.9′	131°04.2′	690.24	571.48	402.43	−33.17
23	No. 4½	32°54.7′	131°04.7′	737.75	571.21	391.30	−34.68
24	No. 5	32°54.6′	131°05.0′	762.65	571.07	385.51	−35.43
25	No. 5½	32°54.6′	131°04.7′	798.07	571.07	377.85	−36.12
26	No. 6	32°54.6′	131°04.4′	825.87	571.07	372.23	−36.26
27	No. 6½	32°54.6′	131°04.2′	859.73	571.07	364.32	−37.51
28	No. 7	32°54.4′	131°03.9′	880.77	570.80	358.92	−38.49
29	No. 7½	32°54.4′	131°03.7′	907.94	570.80	352.37	−39.69
30	No. 8	32°54.2′	131°03.7′	932.81	570.52	347.34	−39.54
31	No. 8½	32°54.0′	131°03.3′	951.47	570.25	343.16	−39.79
32	No. 9	32°53.7′	131°03.1′	967.55	569.84	338.63	−40.73
33	No. 9½	32°53.5′	131°03.0′	1006.10	569.56	331.64	−39.86
34	No. 10	32°53.4′	131°03.1′	1043.50	569.43	323.40	−40.61
35	No. 10½	32°53.2′	131°03.1′	1071.00	569.15	316.59	−41.72
36	No. 11	32°53.1′	131°03.3′	1123.40	569.02	306.04	−41.83
37	No. 11½	32°53.0′	131°03.1′	1150.25	568.88	301.30	−41.14
38	No. 12	32°52.9′	131°03.0′	1150.81	568.74	299.68	−42.51
39	No. 12½	32°53.0′	131°03.5′	1119.02	568.88	308.87	−39.72
40	No. 13	32°52.9′	131°03.9′	1104.70	568.74	311.55	−39.72
41	No. 13½	32°52.7′	131°04.1′	1122.63	568.47	308.65	−38.82
42	No. 14	32°52.6′	131°04.7′	1167.28	568.33	298.92	−39.62

43			No. 14½	32°52.6′	131°04.8′	1192.30	568.33	294.17	−39.45
44			No. 15	32°52.5′	131°05.2′	1241.98	568.19	283.08	−40.61
45	B. M. Kumamato Pref.		No. 2	32°53.8′	131°01.0′	485.7	570.0	454.3	−20.1
46			No. 3	32°53.5′	131°00.3′	532.5	569.6	441.4	−23.4
47			No. 4	32°53.8′	131°00.8′	572.8	570.0	429.8	−27.4
48			No. 5	32°53.4′	131°01.1′	626.8	569.4	417.3	−28.7
49			No. 6	32°53.3′	131°01.5′	660.3	569.3	407.8	−31.5
50			No. 7	32°53.7′	131°01.7′	696.4	569.8	400.4	−32.3
51			No. 8	32°54.0′	131°02.1′	761.7	570.2	386.2	−34.1
52			No. 9	32°53.9′	131°02.6′	888.1	570.1	357.6	−37.7
53			No. 10	32°53.8′	131°02.8′	925.5	570.0	349.7	−38.2
54			No. 11	32°53.8′	131°03.0′	971.5	570.0	339.6	−39.2
55	T. P.	北本		32°55.7′	131°06.5′	548.4	572.5	441.9	−22.6
56		南西原	(匹22)	32°55.5′	131°07.5′	574.2	572.3	442.2	−17.2
57		駄原	(典14)	32°55.6′	131°08.2′	562.6	572.4	448.4	−13.2
58		牧下	(匹25)	32°54.9′	131°07.8′	646.4	571.5	429.8	−14.5
59		高田	(典12)	32°56.9′	131°07.5′	507.3	574.2	452.0	−22.3
60		幡園		32°56.9′	131°06.7′	510.7	574.2	450.2	−23.5
61		役犬原	(匹11)	32°56.8′	131°05.8′	507.2	574.1	448.1	−26.2
62		北黒川	(匹12)	32°56.7′	131°04.9′	502.5	573.9	447.9	−27.1
63		今町		32°57.4′	131°04.8′	492.3	574.9	450.0	−28.0
64		新田	(匹 6)	32°57.8′	131°05.4′	489.3	575.6	451.9	−27.4
65		小倉	(匹 8)	32°58.6′	131°05.1′	523.5	576.6	448.5	−25.1
66		黒流	(后15)	32°58.0′	131°04.2′	483.8	575.7	455.6	−24.9
67		成川	(后16)	32°57.6′	131°03.6′	485.2	575.2	454.2	−25.5
68		中番出		32°58.3′	131°02.6′	479.3	576.1	456.7	−25.1
69		狩尾	(后14)	32°57.1′	131°02.7′	482.8	574.5	457.1	−22.4
70		下湯浦	(后13)	32°59.0′	131°02.4′	481.2	577.1	458.8	−23.6
71		大塚山	(后 8)	32°59.5′	131°02.9′	555.2	577.8	444.7	−23.8
72		火山研究所		32°52.9′	131°00.4′	567.7	568.7	432.2	−24.8
73		岩の上		32°50.5′	131°00.9′	391.6	565.5	474.7	−13.7
74			(典10)	32°50.1′	131°01.5′	370.7	564.9	476.3	−15.6
75		中松		32°49.6′	131°02.1′	386.6	564.2	472.7	−15.4
76		西中原	(典 8)	32°49.8′	131°01.2′	391.1	564.5	477.7	− 9.8
77		松の本	(典 7)	32°49.1′	131°01.7′	425.5	563.5	472.5	− 7.2
78		柏木谷	(典 6)	32°49.1′	131°02.6′	408.1	563.5	474.2	− 9.0
79		小牧	(典 5)	32°48.3′	131°02.0′	532.2	562.4	449.2	− 8.4
80		一の鳥竹	(堂29)	32°48.7′	131°04.4′	462.0	563.0	459.3	−12.8
81		西中郷	(堂25)	32°48.8′	131°05.5′	481.2	563.1	453.9	−14.5
82	S. H.	木村		32°58.4′	131°05.4′	490.	576.3	455.1	−24.7
83		一関		32°49.1′	131°03.9′	437.	563.5	457.5	−20.0
84		両併		32°49.0′	131°06.2′	503.	563.4	447.1	−17.3
85		たかもり駅		32°48.9′	131°07.2′	541.3	563.3	444.7	−12.0
86		あそしもだ駅		32°50.4′	131°01.5′	372.3	565.3	474.8	−17.2
87	一の宮町営道路上		No. 129	32°55.1′	131°06.2′	619.3	571.8	426.4	−23.5
88	〃		No. 178	32°54.7′	131°06.5′	695.6	571.2	411.6	−22.7

89	〃	No. 221	32°54.3′	131°06.6′	762.3	570.7	394.4	−26.3
90	〃	No. 295	32°53.8′	131°06.2′	895.8	570.0	362.8	−30.9
91	道路公団別府阿蘇道路上	(B. M.)	32°58.5′	131°08.3′	661.3	576.4	420.1	−26.1
92	〃	(B. M.)	32°59.1′	131°08.7′	771.1	577.2	397.4	−28.0
93	〃	No. 2404	32°59.6′	131°08.3′	785.5	577.9	394.2	−29.0
94	〃	No. 2304	33°00.5′	131°08.8′	741.3	579.2	408.6	−24.7
95	〃	No. 2221	33°01.2′	131°08.9′	802.2	580.1	395.9	−26.3

φ . Latitude
λ . Longitude
H : Heigh above sea level
γ : Normal gravity value
g : Gravity
$\Delta g_0''$: Bouguer anomaly

Research.

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